PB82-236415

Responses of Developing Estuarine Macrobenthic Communities to Drilling Muds

(U.S.) Environmental Research Lab.
Gulf Breeze. FL

Jun 82

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TECHNICAL REPORT DATA
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1. REPORT NO.	2.	3. REC
EPA-600/J-81-070	Journal Article	PB82-236415

4. TITLE AND SUBTITLE
RESPONSES OF DEVELOPING ESTUARINE MACROBENTHIC COMMUNITIES TO DRILLING MUDS

5. REPORT DATE

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
U.S. Environmental Protection Agency
Environmental Research Laboratory
Office of Research and Development
Gulf Breeze, FL 32561

13. TYPE OF REPORT AND PERIOD COVERED

14. SPONSORING AGENCY CODE
EPA/600-J

15. SUPPLEMENTARY NOTES
Ref. Estuaries 5(2):131-137

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Release to public	unclassified	6
	20. SECURITY CLASS *(This page)*	22. PRICE
	unclassified	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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EPA-600/J-81-070
JOURNAL ARTICLE

Estuaries Vol. 5, No. 2, p. 131–137 June 1982

Responses of Developing Estuarine Macrobenthic Communities to Drilling Muds[1]

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ABSTRACT: The effects of drilling mud, used in oil drilling operations, on development of estuarine macrobenthic communities from settling planktonic larvae were assessed by comparing numbers and species of animals that grew in uncontaminated and contaminated aquaria for 8 weeks. Aquaria contained sand and were continuously supplied unfiltered seawater. Seven lignosulfonate-type drilling muds obtained from an active exploratory platform in estuarine waters were tested consecutively at nominal concentrations of 0.5, 5, and 50 parts per million (ppm) in the water column. Numbers of tunicates, mollusks, and annelids per aquarium were significantly ($\alpha = 0.05$) decreased from control numbers in 50 ppm. Structural differences in communities exposed to 50 ppm from those in the control and lower concentrations were indicated by a decrease in Spearman's measure of rank correlation of species abundance and an increase in the Shannon-Weaver index of species diversity. A total of 13 species occurred in 50 ppm compared to 23 species in each of the other situations. Growth in diameter of *Molgula manhattensis* was significantly affected in all concentrations of mud.

Introduction

Recent demands for new supplies of energy have resulted in increased offshore and onshore exploratory drilling for oil and gas, and also a new emphasis on drilling in inland waters. A buildup of muds on bottom sediments resulting from routine or accidental discharges would be likely to occur in shallow, enclosed inland waters, and would particularly affect benthic communities near these drilling sites. Changes in species composition, density, and structure of benthic macrofauna are considered good indicators of the effects of pollution and stress on marine ecosystems (Swartz 1978).

Drilled cuttings and drilling mud, which is continually recirculated through the borehole to bring up the cuttings, require disposal during drilling in aquatic environments. Most mud is recovered and recycled, but old or excess muds are usually discharged as turbidity plumes and some are lost with the cuttings. Although drilling wastes may be transported for disposal on land, muds from offshore or lake drilling usually have been released into surrounding waters (Sprague and Logan 1979); tons of mud and cuttings have been discharged and deposited on the bottom near offshore drilling sites (George 1975).

In addition to their role in the transport of drill cuttings in the borehole, muds also function to maintain hydrostatic pressure, seal surrounding surfaces, and lubricate the drill bit. Constituents of mud and their amounts vary with drilling conditions, such as type of formation and depth of drilling. However, they generally are water-based mixtures of barite, clay, lignosulfonate, lignite, and smaller amounts of additives to control such factors as bacterial growth, pH, and corrosion.

[1] Contribution No. 413 of the Environmental Research Laboratory, Gulf Breeze, Florida.

0160-8347/82/020131-08$01.50/0

TABLE 1. Data on muds, used in an 8-week exposure of benthic communities, obtained from an active exploratory platform during 8 weeks of operation in a tidal embayment.

Sequence Number	lb per gal	kg per l	%/wt		Drill Depth	
			Solid	Liquid	ft	m
1	9.7	1.16	25	75	15,500	4,726
2	9.9	1.19	27	73	16,200	4,939
3	10.4	1.25	33	67	17,000	5,183
4	10.5	1.26	34	66	18,000	5,488
5	10.5	1.26	34	66	18,570	5,662
6	10.6	1.27	34	66	19,050	5,808
7	11.3	1.35	40	60	19,100	5,823

We tested the effects of lignosulfonate-type drilling muds, used in oil drilling operations in a tidal embayment, on the development of macrobenthic communities which result from settling planktonic larvae.

Materials and Methods

The effects of drilling mud were determined by comparing numbers and species of animals that grew from planktonic larvae in treated aquaria for 8 weeks (September 20 to November 15, 1979) with animals that grew in untreated aquaria. Seven lignosulfonate-type drilling muds were collected at about 8-day intervals from the mud pit of an active exploratory platform during 8 weeks of operation in Mobile Bay, Alabama. These muds were stored in the laboratory at approximately 15° C and tested consecutively (each for 8 days) during our 8-week test. Mud weights ranged from 1.16 to 1.35 kg per l, and depths of drilling ranged from 4,726 to 5,823 m (Table 1). Range of pH was from 11.0 to 11.5.

Our samples of mud contained varying amounts of a possible 30 products that were used in the drilling muds during operation of this well (information provided by Mobil Oil Corporation and IMCO Services). Constituents of these products, in decreasing order of total amounts by weight used in the drilling operation, consisted of (1) barium sulfate (barite), (2) bentonite clay, (3) sodium hydroxide, (4) attapulgite clay, (5) ferrochrome lignosulfonate (with sodium bichromate), (6) ferrochrome lignosulfonate (trivalent chromium bound within lignin molecule), (7) lignite coal, (8) blend of lignosulfonates, polymers, and sodium carbonates, (9) sodium carbonate, (10) calcium hydroxide, (11) sodium chromate, (12) polyanionic cellulosic polymer, (13) glycerol mono-oleates and mixed long chain alcohols, (14) sodium acid pyrophosphate, (15) ground pecan shells, (16) ground mica, (17) chrysotile asbestos fibers, (18) calcium oleate and asphalt, (19) blend of zinc sulfonate, sodium nitrilotriacetic acid, and zinc carbonate, (20) blend of water dispersable asphalts, (21) sodium polyacrylate polymer, (22) sulfonated asphaltene, (23) phosphoric acid tributyl ester, (24) blend of nut shells, cellophane, paper, and mica, (25) insoluble aluminum salt of octadecanoic acid, (26) modified alkanolamid and sodium acid pyrophosphate, (27) blend of phosphoric acid tributyl ester, alcohol, and a refined hydrocarbon, (28) sodium polyacrylate blend, (29) sulfonated fatty acid derivatives, and (30) polymeric sodium polyacrylamide. In addition, the biocide, pentachlorophenol, reportedly was used as a component of the packer fluid, but was not employed in the drilling fluid.

We used four acrylic plastic apparatuses, each consisting of a central constant-head box (20 cm × 20 cm × 13 cm high) from which eight aquaria (40 cm long, 10 cm wide, 12 cm high) extended (Fig. 1). Aquaria were filled to a depth of 5 cm with clean silica sand (particle size, 200 to 800 μm) dredged some months previously from Santa Rosa Sound, FL, covered by 3 cm of water (depth was maintained). Seawater with its constituent plankton was delivered continuously at 2 l per min to the constant-head boxes. Flow to each aquarium was maintained at 200 ml per min by adjusting the height of a 3-mm diameter hole in the wall of the constant-head box. Water left each aquarium through a notched end opening. Illumination consisted of alternate 12-h periods of light and darkness. Salinity of the water averaged 25‰ (18 to 32‰); temperature, 22 °C (14 to 27 °C).

Desired dilutions of mud-seawater mixtures in 150-l reservoir tanks were metered by peristaltic pump through tubing into the constant-head boxes of the treated apparatuses. One apparatus of eight aquaria received no mud, only seawater, and served as the control. Muds in the reservoir were maintained in suspension by continuous

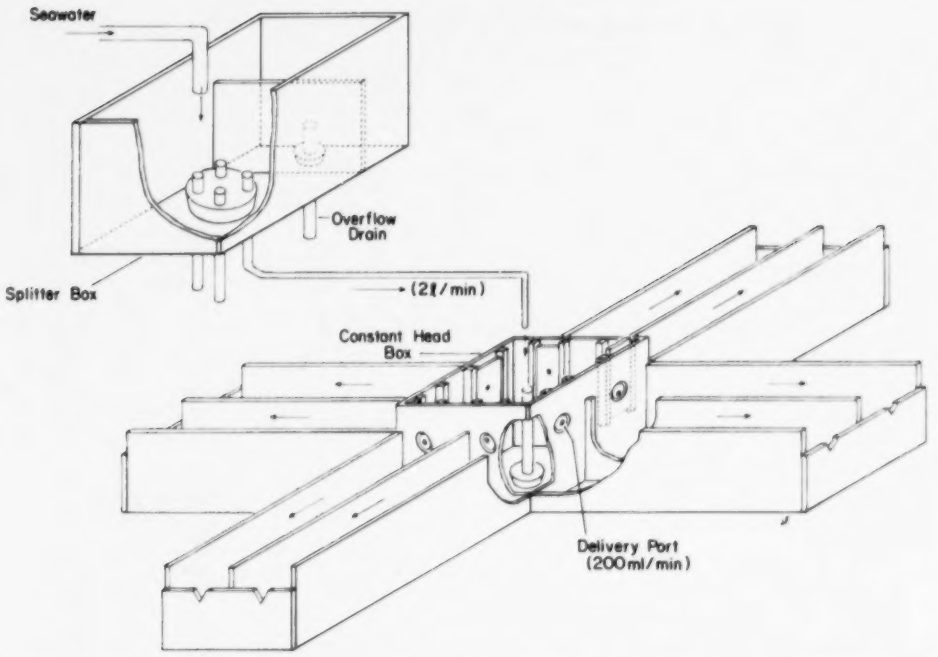

Fig. 1. One of four identical apparatuses of eight aquaria, extending from the splitter box shown, used to test the effect of drilling muds on development of estuarine animal communities.

mixing with submersible pumps; air bubbles released from small air-stones in the constant-head boxes kept the muds suspended during passage to the aquaria. The dilutions tested corresponded to nominal concentrations of 0.5, 5, and 50 parts per million (ppm, μl per l).

After 8 weeks, animals were collected by siphoning the contents of the aquaria into a 1-mm-mesh sieve, preserved, and later identified. Results are presented as pooled data from each drilling-mud concentration and the control. One-way analysis of variance (SAS, 1979) and Dunnett's test (Ostle 1963) were used to compare numbers and species of animals in control and treated aquaria ($\alpha = 0.05$). Spearman's measure of rank correlation (Ostle 1963) was used to compare the order of abundance of species in the control with each concentration of drilling mud. Only those species represented by a total of at least three individuals were used in the calculations. The Shannon-Weaver (1963) index of species diversity also was calculated ($\log_2$) for the control and treatments to assess any differences in community structure. To determine if drilling mud affected growth in diameter of tunicates, those collected from the control and each treatment at the end of exposure were measured on the basis of numbers larger than 5 mm and those 5 mm or smaller. Analysis of variance and Dunnett's test ($\alpha = 0.05$) were used to compare the percentages of tunicates in each size group from the control and those in the treatments (data from the eight replicates were pooled).

Results

The harvest at 8 weeks yielded 4,086 animals representing 35 species of 8 phyla (Table 2). Numerically dominant phyla were Chordata, Mollusca, and Annelida.

Abundance of animals was decreased significantly ($\alpha = 0.05$) by 50 ppm drilling mud (Table 3). Average numbers of individuals and species per aquarium were significantly fewer in aquaria that received 50 ppm than in control aquaria or those that received 0.5 ppm or 5 ppm. A total of only 13 species

TABLE 2. Animals collected from control aquaria and from aquaria exposed to drilling muds for 8 weeks. Replicates were pooled.

Taxon	Control	Drilling Mud (ppm)			Total Animals
		0.5	5	50	
CHORDATA					
Molgula manhattensis	968	1,313	836	3	3,120
MOLLUSCA					
Diastoma varium	100	102	147	0	349
Laevicardium mortoni	58	62	62	10	192
Acteocina canaliculata	15	13	7	12	47
Mitrella lunata	7	4	6	2	19
Anadara transversa	6	5	4	0	15
Lyonsia hyalina floridana	3	3	8	0	14
Mulinia lateralis	4	3	4	0	11
Ervilia concentrica	2	1	5	0	8
Amygdalum papyrium	0	1	1	0	2
Musculus lateralis	0	0	2	0	2
Abra aequalis	1	0	0	0	1
Chione latilirata	1	0	0	0	1
Crassostrea virginica	0	1	0	0	1
Cyrtopleura costata	1	0	0	0	1
Jouannetia quillingi	0	1	0	0	1
Tagelus divisus	1	0	0	0	1
Trachycardium muricatum	0	0	1	0	1
Total mollusks	199	196	247	24	666
ANNELIDA					
Armandia maculata	31	28	36	7	102
Neanthes succinea	19	31	17	10	77
Capitomastus aciculatus	10	10	10	8	38
Polydora ligni	2	0	2	3	7
Polydora socialis	4	0	0	1	5
Cistenides gouldii	1	2	1	0	4
Eupomatus dianthus	0	1	0	0	1
Lepidonotus variabilis	0	0	1	0	1
Sabella melanostigma	0	0	1	0	1
Total annelids	67	72	68	29	236
ARTHROPODA					
Balanus improvisus	10	3	3	0	16
Neopanope texana	2	2	3	3	10
Balanus amphitrite niveus	0	1	1	0	2
Oxyurostylis smithi	0	0	0	1	1
Pagurus longicarpus	0	1	0	0	1
Total arthropods	12	7	7	4	30
COELENTERATA					
Aiptasia pallida	5	9	5	4	23
ECHINODERMATA					
Synaptula hydriformis	5	0	0	3	8
PLATYHELMINTHES					
Polycladida	0	3	0	0	3
ALL PHYLA					
Individuals	1,256	1,600	1,163	67	4,086
Species	23	23	23	13	35

TABLE 3. Average density of animals and number of species per aquarium (range in parentheses), collected from control aquaria and aquaria exposed to drilling muds for 8 weeks.

			Drilling Mud (ppm)					
	Control		0.5		5		50	
Phylum	No.	Sp.	No.	Sp.	No.	Sp.	No.	Sp.
Chordata	121.0 (47–254)	1.0 (1)	164.1 (38–385)	1.0 (1)	104.5 (3–367)	1.0 (1)	0.4* (0–2)	0.2* (0–1)
Mollusca	24.9 (10–36)	4.8 (3–8)	24.5 (11–61)	4.6 (4–5)	30.9 (4–77)	5.2 (3–8)	3.0* (0–8)	1.5* (0–3)
Annelida	8.4 (4–11)	2.8 (2–4)	9.0 (5–15)	3.0 (2–4)	8.5 (5–14)	3.5 (2–5)	3.6* (1–8)	2.4 (1–4)
Arthropoda	1.5 (0–7)	0.6 (0–2)	0.9 (0–4)	0.6 (0–2)	0.9 (0–2)	0.9 (0–2)	0.5 (0–1)	0.5 (0–1)
Coelenterata	0.6 (0–2)	0.4 (0–1)	1.1 (0–3)	0.6 (0–1)	0.6 (0–2)	0.4 (0–1)	0.5 (0–2)	0.4 (0–1)
Echinodermata	0.6 (0–2)	0.6 (0–2)	0 (0)	0 (0)	0 (0)	0 (0)	0.4 (0–1)	0.4 (0–1)
Platyhelminthes	0 (0)	0 (0)	0.4 (0–1)	0.4 (0–1)	0 (0)	0 (0)	0 (0)	0 (0)
All Phyla	157.0 (88–271)	10.1 (6–15)	200.0 (70–460)	10.2 (9–13)	145.4 (17–435)	11.0 (7–13)	8.4* (4–17)	5.4* (3–9)

* Significantly less than control at 5% level; significance is indicated only for the three most abundant phyla.

occurred in 50 ppm compared to 23 species in the control and in other treatments.

Communities exposed to 50 ppm drilling mud were structurally different from those in the control and lower concentrations. Spearman's rank correlation values for species abundance as compared to control (1.00) were 0.92 (0.5 ppm), 0.82 (5 ppm), and 0.47 (50 ppm). The Shannon-Weaver index of species diversity ranged from 1.21 to 1.63 for the control aquaria and those contaminated by 0.5 ppm or 5 ppm mud, but increased to 3.35 for the 50 ppm exposure (Fig. 2). Community evenness (relative number of each species) increased from 0.33 for the control to 0.90 for the 50 ppm exposure; richness (number of species minus one relative to the $\log_2$ of number of individuals) only ranged from 1.99 to 2.16 among exposures (Fig. 2).

Number of individuals of chordates (all *Molgula manhattensis*), mollusks (primarily *Diastoma varium* and *Laevicardium mortoni*), and annelids (primarily *Armandia maculata* and *Neanthes succinea*) per aquarium were significantly decreased in 50 ppm, as were the number of species of mollusks. The tunicate, *Molgula manhattensis*, was particularly sensitive. Only three tunicates were collected from aquaria containing 50 ppm compared to totals ranging from 836 to 1,313 individuals from the control and lower concentrations. In addition, growth of tunicates in 0.5 and 5 ppm drilling mud was affected. The average percentage of animals larger than 5 mm in diameter in

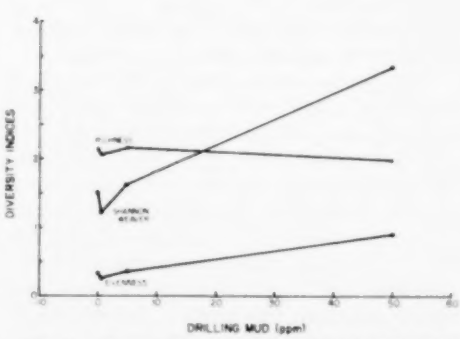

Fig. 2. Shannon-Weaver index of species diversity, richness, and evenness in control aquaria and in aquaria contaminated with 0.5, 5, or 50 ppm drilling mud.

the control group (42%) was significantly greater than that of animals in 0.5 ppm (26%) and in 5 ppm (28%).

At the end of 8 weeks, a 2-mm layer of the solid components of drilling mud had accumulated over the sand in aquaria exposed to 50 ppm. Accumulation was less than 1 mm at the lower concentrations.

Discussion and Conclusions

Our results and those of previous studies indicate that the abundance of benthic animals can be significantly affected by drilling mud. We found that the numbers of tunicates, mollusks, and annelids from aquaria exposed to 50 ppm mud in water were less than control numbers. In addition, rank correlation of species abundance differed between control and 50 ppm aquaria, and species diversity increased in communities exposed to 50 ppm. Increase in diversity (species more equally abundant) occurred because the species which were abundant in control aquaria were particularly sensitive to drilling mud. Rubinstein et al. (1980) also collected fewer mollusks and annelids from developing macrobenthic communities exposed to 100 ppm of a series of drilling muds obtained from an active exploratory platform. Whole drilling mud or barite (a mud-weighting agent and major component of mud) have shown impact on settling benthos produced by substrate covering as well as sediment alteration (Tagatz and Tobia 1978; Tagatz et al. 1978). A cover of drilling mud (2 mm) or barite (5 mm) reduced numbers of mollusks, annelids, arthropods, and coelenterates; a mixture of contaminant and sand (1:10 sand) reduced numbers of annelids and coelenterates.

Changes in animal communities exposed to drilling muds could be due to toxic constituents, such as some biocides, or to barite and clay components that cause sediment load in the water column and change sediment granulometry. Chlorophenol-type biocides were found to be very toxic (parts per billion range) to developing macrobenthic communities (Tagatz et al. 1979). High sediment load might be expected to particularly impact animals such as tunicates and barnacles that make their living by constantly filtering the water. George (1975) found few barnacles on test panels suspended in the turbidity plume of drilling mud and suggested that the influence of these plumes on sessile organisms is a physical phenomenon that interferes with feeding and reproduction. In the present study, physical alteration of the substrate occurred when drilling mud accumulated over the sand in the test aquaria. The relation of sediment type to the character of settling benthos is well-documented (Bloom et al. 1972; Gray 1974, Johnson 1970), and the type of animals that settle and grow in a particular locality appears to be related to the physical composition and organic content of the sediment (Thorson 1957).

Reduction in the density of macrofauna also may be due to secondary effects of drilling muds that result from changes in interspecific interactions and in meiofaunal populations. One of many interactions that drilling mud could alter is the competition for surface space between burrowing and tube-building forms of polychaete worms; Woodin (1974) found that the abundances of these forms were highly correlated in Mitchell Bay, Washington. Studies have also shown changes in meiofaunal populations when developing estuarine benthic communities are exposed experimentally to certain drilling mud constituents. Differences in meiofaunal densities from control densities occurred at various concentrations of pentachlorophenol (Cantelmo and Rao 1978) and barite (Cantelmo et al. 1979).

Although drilling muds and their real or potential environmental concentrations are highly variable, we believe that our data from testing a simulated estuarine situation with estuarine drilling muds indicate that muds could adversely affect colonization of estuarine areas by planktonic larvae. Concentrations tested in this experiment were lower than some of those found near the source of discharges from an offshore well studied by Ecomar (1978). Changes in the relative abundance of settling organisms could lead to local reduction of recruitment, changes in the food webs of resident animals, and an interruption in community stability. These factors should be included in any consideration of the environmental impact of aquatic disposal of drilling wastes.

Acknowledgments

We thank Mobil Oil Corporation for supplying daily drilling records and for allowing us to obtain samples of drilling mud, and IMCO Services for providing descriptions of their products.

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